

## **Section 3.3**

# **Load Drop of a Pretreatment Pump (Out of Cell)**

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## Section 3.3

# Pretreatment Pump Drop (Out of Cell)

### 3.3.1. Work Identification

This report demonstrates an application of the integrated safety-management process to an example of pretreatment pump drop (out-of-cell). This report focuses on the control of hazards associated with dropping a flask containing a contaminated HLW pretreatment pump during transport from its cell to the maintenance facility within the pretreatment area. The term “out-of-cell” indicates that at the time of the drop, the pump cartridge is removed from the normal (primary) confinement of its casing and the normal secondary confinement afforded by the cell.

The concept of transporting the pump results from the developing Tank Waste Remediation System – Privatization (TWRS-P) design. The maintenance philosophy for the pretreatment process pumps and valves was outlined in a report on plant equipment maintenance philosophies (Richardson 1997) issued within Part A of the contract (DOE-RL 1998a) and subsequently reviewed in a report specific to pretreatment (Richardson 1998). The review was commissioned in the light of:

- Revisions to the flow sheets and resultant revised shielding assessments
- Additional information on equipment reliability data
- Additional design studies and cost evaluation exercises
- Reviews of the mechanical pumps with an aim of maximizing the use of maintenance free fluidic devices as alternatives. This has benefits in terms of plant availability, operator dose, and waste reduction.

Implementing the results of the pretreatment maintenance strategy document (Richardson 1998) will necessitate changes to the facility layouts issued as part of Part A of the Contract. A change required will be the replacement of some equipment “in-situ maintenance” facilities (e.g., shielded glovebox bulges) and the introduction of a “remote decontamination and maintenance facility.”

The design concept is for items which are to be moved to the maintenance facility to be withdrawn from cell into a shielded flask (or cask) which is then transported by crane to the maintenance facility. The *Hanford TWRS Plant Equipment Maintenance Philosophy* document (Richardson 1997) will be revised accordingly under Part B1 of the Contract.

Three classes of contaminated equipment are expected to be moved using the pretreatment facility crane and flask; minor maintainable components, such as valves, larger maintainable items, such as pumps, and failed ultrafilter tubes destined for disposal. The bounding consequences would be expected to be associated with the ultrafilter, but it is anticipated that the frequency of this move will be very low. Of the maintainable items, pumps are expected to be bounding in terms of consequence, having a greater potential

for activity retention than valves. The particular pump addressed in this report has been chosen as a probable design basis event for the class of load drop of maintainable items.

Since the transport of the pretreatment pump was not considered for the Part A design, there is no discussion of this activity in the Initial Safety Assessment Report (ISAR) (BNFL Inc. 1998c), Hazard Assessment Report (HAR) (BNFL Inc. 1998b), nor the Technical Report (TR) (BNFL Inc. 1998d). HAR event identifier 1/27 (BNFL Inc. 1998b, p. 5-40) does note a similar event, the dropping of ultra-filter tubes. This identifier notes that "assessment of mechanical handling operations will be required, together with full hazard evaluation study of Mechanical Handling Diagrams (MHD)." Such an analysis would include the consideration of the dropping and impacts of all loads and would identify the requisite control strategies and SSCs applicable to all lifts.

The dropping of a pretreatment pump, as considered for this worked example, is an interim evaluation of one hazard that would be included as part of that MHD study in support of the PSAR for TWRS-P.

### **3.3.1.1. Key Process and Design Parameters**

#### **3.3.1.1.1. Process**

The pretreatment of LAW and HLW feeds will be undertaken in the pretreatment area. The pretreatment facility basically provides the stock to feed the vitrification processes.

The feed to the pretreatment area has been classified into three LAW envelopes: A, B and C. HLW feed is classified as envelope D. (Page, and others 1998). It would be expected that greater doses on loss of containment would be associated with the higher transuranic content of HLW (envelope D) feed, and this example is based on a pump handling HLW material. The contract defines these envelopes in terms of constituent moles of activity per mole of sodium. Envelope D feed may range in solids content (where most of the transuranic activity would be concentrated) from 10 g/L to 200 g/L of non-volatile oxides. The composition of the unwashed solids component for envelope D is provided in the contract (DOE-RL 1998a).

The HLW is delivered to a receipt vessel. From this vessel it is transferred to the ultra-filter system, where it is recirculated through ultra-filters to wash and concentrate the solids stream to 25 wt% . The resultant slurry is then transferred to a holding tank prior to discharge to the HLW melter system.

#### **3.3.1.1.2. Pump Design**

For this example TWRS-P pump P32001 has been chosen. It is the largest pump which handles the slurry at the maximum solids concentration. Larger pumps in the pretreatment facility handle much less active material (Gibbs, 1999). **Design Assumption.** P32001 is a vertically-oriented centrifugal pump. It has a duty of 1985 gpm (451 m<sup>3</sup>/h) at a pressure of 65 psi (4.5 bar). The weight of the pump is thought to be about 1 ton. A typical BNFL pump of this type is shown diagrammatically at Figure 3.3-1.

All pump-wetted parts, including the impeller, will be manufactured in austenitic stainless steel, provisionally grade 304 (low carbon) or 316 (low carbon). The surface finishes will be selected to minimize plated-out activity. The potential to retain residual liquors prior to pump withdrawal is minimized by the design of the pump and pump housing, providing natural self-draining properties. These

are aspects of as low as reasonably achievable (ALARA) design related to the remote maintenance facility operation, but have a bearing on the drop hazard.

#### **3.3.1.1.3. Handling Equipment**

The conceptual design for handling the pump involves a shielded flask and crane. The requirement to provide biological shielding and containment, i.e., flasking, for the transport of TWRS pretreatment pumps is an ALARA consideration and stems from the review of maintenance strategies for pretreatment (Richardson 1998), (Page, and others 1998). The design incorporates a gamma gate and system of mechanical and electrical interlocks to prevent the flask being lifted from the cell roof without the double doors being closed to shield and contain both the flask and the cell. A typical BNFL flasking system for such duty is shown in Figure 3.3-5. The weight of the flask for TWRS is not yet known, but based on BNFL experience of similar duties, it would be on the order of 20 tons.

The crane is an electrically operated overhead travelling (EOT) design. The flask attaches to the crane using a purpose-designed lifting beam. The lift height would typically be limited to no higher than is required to access the gamma gate and clear pump motors etc; on the order of 3 to 6 ft (1 to 2 meters).

#### **3.3.1.2. Interfaces**

This is an activity associated with the maintenance of pumps which have been taken offline and has no primary process interfaces for normal operation beyond the requirement for isolation of the affected routing.

There is an interface with the operation and availability of the remote maintenance facility. To satisfy ALARA requirements for operation of the maintenance facility it is necessary that the activity carried forward with the pump be reduced as far as reasonably achievable. To achieve this, pumps are flushed in situ prior to withdrawal. In addition a wash ring provides further solids removal during withdrawal, and also removes contaminated liquor residues from the earlier flush. Removed pumps are radiation monitored, and if activity levels are excessive they are returned to their casing for further flushing/washing.

The pipework system from which the pumps will be removed is under negative pressure as induced by the vessel ventilation system, and the area through which the pump will be transported is at a higher pressure, though still at depression, induced by the C2 ventilation system. The vessel ventilation extract is filtered before discharge. The C2 extract is unfiltered at discharge.

Equipment in the cells below the transport area of the flask and pump includes numerous valves, pumps, ultra-filters, and tanks associated with the ultra-filter circuit. Penetrating the floor (which is also the cell roof) and in turn impacting such equipment could result in additional consequences to those expected from the simple drop of the pump.

#### **3.3.1.3. Operating Environment and Setting**

The design of the pretreatment building allows access to pumps located in concrete process cells below elevation 0 m (see Figure 3.3-2). The roofs of the cells have access plugs located at floor elevation 0-m. The equipment is arranged essentially in two parallel rows and the route to the maintenance area is north along Section Line 3. The maintenance facility is located within the pretreatment building. See

Figure 3.3-3 and Figure 3.3-4. The maximum credible drop for lifted equipment is limited to the lift height, i.e. all the cell access plugs are on the same level. **Design Assumption.**

The area through which the pumps are transported is an operating area classified as being of low contamination and radiation hazard status. It presents no particularly onerous physical conditions for the equipment or for operator occupancy to support the activity.

The removed pumps will have normally been in an alkaline environment, but may have been subjected to an acidic wash prior to removal. They may therefore contain either acid or alkaline residue (along with the source term activity), and the ability of the flask design to cope with this is a **Safety Function.**

The design concept for pump removal in the context of its process can now be summarized (see schematic diagram at Figure 3.3-5):

Pumps are first flushed. Pumps will be transferred to the maintenance facility in a bottom entry flask. The flask using its integral winch and grab raises the pump. As it is raised a wash ring is operated to further remove activity. The pump then passes a radiation monitor on its way into the body of the flask. Alarm of the monitor will prompt operators to lower the pump back into its casing and repeat the flush and wash. Closure of the flask and gamma gate double door assembly releases interlocks permitting the building crane to hoist the flask off the cell mobile gamma gate. The flask is then moved across the cell roof and placed in its position on the receipt gamma gate at the maintenance facility. The gamma gate and flask double door assembly is opened, and the pump lowered from inside the flask and on to the receipt frame within the maintenance facility. The flask grab is then retracted and the gamma gate and flask door closed.

#### **3.3.1.4. Applicable Experience**

The envisioned remote maintenance strategy is based on one that is currently employed at BNFL's Sellafield site. The activity is employed at the Site Ion Exchange Effluent Plant (SIXEP) and the Enhanced Actinide Removal Plant (EARP) where the pumps are transported by flasks. Maintenance operations have been performed safely, effectively, and reliably at both plants for 13 and 9 years respectively.

BNFL's preferred means of moving flasks at the Sellafield site is to use bogies mounted on rails. This is not practical in certain applications where movement to different elevations or a high degree of positional flexibility is required. Plant and process layout constraints may also make the use of a floor mounted bogie impractical, as in the case of EARP. In such cases the preferred method is to use high integrity cranes. BNFL has gained many years experience in the design and safe operation of such cranes. The Sellafield Reliability Database (BNFL plc 1998) indicates that there have been more than 3 million lifts using cranes to handle flasks with no free fall failures.

An informal survey was made to determine current industry practice vis-a-vis lifting and transporting heavy active loads within U.S. nuclear facilities. The systems in use fall into two main categories (though there are others): electrically-operated, overhead-traveling cranes or wheeled or tracked lifting vehicles.

It was found that in some U.S. operations, radioactively contaminated loads (i.e., active items of remotely maintainable equipment such as pumps, valves, and ultrafilters) are not placed in a flask before transport, facility design permitting (i.e., provision of a shielded route). The load is lifted from its position in the facility, transported to a decontamination cell, decontaminated, and then transported to its final destination

(e.g., co-located maintenance facility, for instance). Where radiation shielding of the load is required, due to lack of a shielded route, it is first loaded into a flask. Flasks are of either the top-loading or bottom-loading configuration depending upon the intended application.

Wheeled transport of loads about a facility may be accomplished by a transport bogie. A transport bogie is a four- wheeled electrically driven standard gauge rail-mounted vehicle that is used to transport flasks or other equipment. Bogies are fabricated of steel and powered via a reeling drum and controlled by a pendant or remote push button. Another wheeled transporter is a “strada-carrier.” It is similar to the transporters used at seaports to move containerized cargo on and off ships. It is solid tire transporter that has a hoisting mechanism built in. The “strada-carrier” does as its name implies; it straddles the load to be transported, lifts it, and carries it to its destination. The system has considerable space requirements.

Individuals with specific historical knowledge of Hanford Site hoisting operations were contacted to gain an overview of common Hanford practices. Individuals with knowledge of K-Basin, Fast Flux Test Facility (FFTF), B-Plant, and the canister storage building were asked to relate their experiences. There is a similarity as to the type of equipment and procedures used for lifting heavy radioactive loads in nuclear-related facilities. The most prevalent method employed was (is) some type of overhead bridge or gantry crane coupled with, when necessary for radiological safety, a flask (or cask) for ALARA purposes.

Individuals at Defense Waste Process Facility (DWPF) at Savannah River were questioned on their use of flasks and cranes in moving radioactive materials. Movement of equipment for maintenance purposes occurs in “canyons,” in two stages, and without using a flask. Components are moved first to a decontamination facility, then on to a maintenance facility. Canisters of vitrified waste are moved to an interim storage facility in a bottom loading shielded cask transporter much like the “strada-carrier” noted earlier. The canisters present a radiation hazard from direct radiation but present little in the way of a radioactive inhalation hazard.

## 3.3.2. Hazard Evaluation

### 3.3.2.1. Hazard Identification

For this example, the hazard effects arise from external whole body irradiation dose or inhalation dose from released radioactive material. The individual(s) most likely affected from such an event would be the local facility operators, with lesser consequences for the co-located worker and the public. The drop also presents damage potential for the floor (cell roof) and components both on and below it.

### 3.3.2.2. Event Sequence

The event is the dropping of a flask containing a pump, due to crane failure or accident, while in route from the pump’s previous cell location to the maintenance facility. It is assumed that only one lift, while carrying the active load, is necessary to perform this activity. **Design Assumption.** The flask fails and releases the pump. Activity carried on the pump is disturbed by the impact and escapes into the operating area and ultimately the external environment.

Further development of the event sequence could occur in two ways. The flask could penetrate the 0-m level floor (which is the roof of cells beneath). This could result in damage to plant in the cell beneath and

further release of activity contained in that plant. It might also lead to damage to Important to Safety equipment with implications for the control of other hazards.

The flask could also fall onto, or topple onto, plant and equipment located on the 0-m level. Again, this might cause a further release of activity. It might also lead to damage to Important to Safety equipment with implications for the control of other hazards.

The current status of design information does not allow either of the two developments of the event sequence noted above to be fully analyzed and have detailed control strategies developed for them at present. In the interim, the safety functionality of the strategies in preventing significant increase of consequences from damage caused by the dropped flask, is assumed. **Safety Function.** This topic is discussed more fully as an **Open Issue**.

Three related hazards are also noted which relate to, but are not part of, this event sequence. These are (i) collision of the flask with other equipment during the move (but without load drop), (ii) drop of the pump back into the cell or maintenance facility during transfer into or out of the flask, and (iii) drop of the pump within the flask (from the internal flask hoist). These will be addressed in appropriate hazard evaluations. **Open Issue.**

For the purposes of this example the event sequence is limited to consequences arising from activity escape from the flask.

### 3.3.2.3. Unmitigated Consequences

Details of the consequence calculation are presented in Calculation W375-NS00003 (Smith unpublished). The following text and table summarize the results of the consequence calculation:

#### Facility Worker

Direct radiation exposure at 1 m for one minute = 0.04 rem

The inhalation dose for the initial release one minute exposure = 46 rem

The total dose for the facility worker = 46 rem + 0.04 rem = 46 rem radiation severity level (SL-1)

#### Co-located Worker

Inhalation Dose = 0.07 rem (SL-4)

#### Public

Inhalation Dose =  $1.1 \times 10^{-4}$  rem (SL-4)

#### Unmitigated Dose Consequences<sup>a</sup>

Population	Dose (rem)	Severity Level
Facility Worker	46	SL-1
Co-located Worker	0.07	SL-4
Public	1.1 x 10 <sup>-4</sup>	SL-4

Note:

a. Dominant pathways selected in each case.

Unmitigated consequence calculations take no credit for the flask containment. The worker is exposed to direct radiation shine from the contaminated pump and from inhalation of radioactive contamination released from the pump.

The potential consequences for solids from tanks 241-AZ-101 and 241-AZ-102 (which are the highest active inventory HLW tanks) were considered and the worst case ( 241-AZ-101) used.

Assumptions made were:

1. The pump is self-draining but not flushed or washed. Residual contamination is dried solids which fill voids and coat the available surfaces. It is conservatively assumed that the pump has been offline for some time prior to maintenance, thus allowing the solids to dry. Design details for TWRS pumps are not yet available. A design of a similar pump with similar duty on existing BNFL plant has been used in the estimation of hold-up for consequence assessment. Voids were assumed filled. A surface coating depth was assumed to be 1.5mm based on engineering judgement, giving a total volume of 2 liters (Gibbs 1999). **Design Assumption.** BNFL has no information at present on activity loading of unwashed pumps, since no pumps have been removed without prior washing in the analogous UK EARP facility. There is a direct linear sensitivity of event consequences to pump activity loading. Whilst it is believed that the assumption made is conservative, the possibility of obtaining more direct evidence from either operating plants or simulation is an **Open Issue**.

The airborne release fraction (ARF) from the flask is  $1.0 \times 10^{-3}$  and respirable fraction (RF) is 0.1. The ARF is the bounding value identified in DOE Handbook 3010 (DOE 1994) for suspension of powder-like surface contamination by shock-vibration. DOE Handbook 3010 (DOE 1994) recommends a RF of 0.1 for clumps/piles of powder due to the forces necessary to deagglomerate and disperse the material. The material remaining in the pump is expected to be agglomerated so the RF of 0.1 is judged appropriate. If the material were loose or free flowing, then the majority of it would have fallen off as it dried, or during removal. Its presence post-removal can only be accounted for by adherence of particles to one another. The ARF is conservative compared to the ARF for concentrated solutions and slurries which range from  $2 \times 10^{-5}$  to  $5 \times 10^{-5}$ .

2. The contamination release is uniformly distributed in a rectangular volume 2 m x 2 m x 2 m high (8 m<sup>3</sup>) (i.e., a cuboid breathing zone surrounding an approximately 2-m tall operator) consistent with the assumption the worker is adjacent to the flask. The worker is exposed to this concentration whilst he remains in the vicinity (i.e., no credit is taken for plate-out or dispersion).
3. The worker exposure occurs for 1 minute prior to evacuation. The drop is obvious to the worker and the worker is trained to evacuate in the event of a dropped load, irrespective of whether there is any apparent release or any operation of area activity alarms. **Operational Assumption.** The probability

of failing to evacuate within 1 minute is considered negligible. Procedural requirements ensure that the operator does not stand in the hazard zone of the suspended load. **Operational Assumption.**

4. The radionuclide concentrations in the waste received from tank 241-AZ-101 is based on the waste inventory in Appendix D of WHC-SD-WM-ER-410, "Evaluation to Establish the Best-Basis Inventory for Double-Shell Tank 241-AZ-101. The radionuclide concentrations in the waste received from tank 241-AZ-102 is based on the waste inventory in Appendix E of WHC-SD-WM-ER-411, "Evaluation to Establish the Best-Basis Inventory for Double-Shell Tank 241-AZ-102." The sludge volumes were based on the current tank sludge volumes. The entire tank active inventory was assumed to reside in the sludge.
5. Direct radiation dose was calculated assuming the operator to be 1m from the source. This is bounding for whole body dose from a ground level source to an operator approximately 2-m tall.

#### 3.3.2.3.1. Severity Level

The drop of the pump is Severity Level 1, based on the potential consequences to the facility worker. The target frequency associated with Severity Level 1 is  $10^{-6}$  per year.

#### 3.3.2.4. Frequency of the Initiating Event

Cranes can drop loads for a number of reasons. The majority of load drops can be ascribed to failure of the wire ropes, through either overstressing or mechanical damage, with some further drops due to failure of hoisting machinery. This in itself though is normally an indication that one or more of the automatic systems or procedural controls designed to protect the rope from overstressing or mechanical damage, or to hold the rope on failure of the hoist, has failed. In using failure frequency data for lifting equipment it is necessary to be aware of the protective systems and controls that have been applied, and therefore underpin the data.

In order to define a frequency estimate for dropping a pump, actual data on crane reliability from BNFL's UK Sellafield operations has been employed.

BNFL's Sellafield experience with the operation of electrical overhead traveling cranes for flask removal and transfer as well as other similar operations is cited (BNFL plc 1998). Based on over 30 years of operation and over 5 million lifts for all crane types, the recommended probability of a falling load is estimated as  $3 \times 10^{-6}$ /lift for an industrial crane and  $1 \times 10^{-6}$ /lift for a "high integrity" crane, both meeting the design requirements for such cranes at Sellafield. This data includes slow, higher speed, and unrestrained falls. It includes individual as well as common cause equipment failures, and possible human-caused errors, that could have resulted in a load drop event.

Such estimates may be conservative in relation to the generation of the assumed consequences, since only unrestrained falls would be expected to be capable of giving rise to them. There has been no instance of an unrestrained fall from any crane at Sellafield during nuclear operations.

Equivalent data for cranes built and operated to U.S. standards and procedures has not yet been identified and analyzed. (It is known that a U.S. parallel to the "high integrity" crane exists, referred to as "single failure proof" and a comparison of the standards for the two cranes is discussed in Section 3.3.4.6). It is

acknowledged that this remains an issue for full confidence in estimation of event frequency. The matter is recorded as an **Open Issue**.

For this example UK data will be employed. To achieve this “expected” experience at TWRS would require that the persons performing the operations have similar training and competency as personnel at Sellafield, that similar procedural guidance be used, and that the crane design (e.g., load margin, redundancy of components and other design safety features) and maintenance be similar to that used at Sellafield. **Operational Assumption, Design Assumption.**

There are 14 pumps designated for removal for maintenance in the pretreatment facility. Maintenance of a pump is expected 13 times per year on average. **Design Assumption.** Predicted pump failure data, primarily due to mechanical seal failures, taking account of duty, which influences failure rate, (Richardson 1998), are shown below:

Duty	Pump Identification Number (P.I. No.)	No. Failures per Year
Continuous	P13001*	2
Continuous	P13003*	2
Continuous	P12004	2
Intermittent	P28301	0.5
Intermittent	P28302	0.5
Intermittent	P28303	0.5
Intermittent	P28304	0.5
Continuous	P26001	2
Continuous	P32001*	2
Intermittent	P14001*	1
<b>Total No. Failures per Year</b>		13

\* Denotes duplicated (i.e., duty/standby) device

With the expected 13 lifts per year, the estimated frequency of a load drop can be annualized by multiplying the failure probability per lift times the expected number of lifts per year. This results in an expected frequency of  $13 \times 3 \times 10^{-6} = 4 \times 10^{-5}/y$  for the industrial crane, or  $13 \times 1 \times 10^{-6} = 1.3 \times 10^{-5}/y$  for a “high integrity” crane.

This approach is conservative in terms of event risk, since the dropping of other pumps would be expected to have consequences at worst equivalent to but generally much lower than those for P32001.

### 3.3.2.5. Common Cause and Common Mode Effects

Power failure must not be a potential cause of load drop, neither must a crane motor or control system electrical fire or any consequential damage from it. This will be reflected in the crane design. **Safety Function.** No other common cause or mode effects were identified as likely to be significant contributors to accident frequency. When considering common nuclear practices for minimizing corrosion, performing

maintenance, etc., the requirement for these is to be equivalent to the Sellafield practices which underpin the frequency data as stated in Section 3.3.2.4. This topic will be considered further under the integrated safety management process as detail design develops.

### **3.3.2.6. Natural Phenomena Hazards and Man Made External Events**

#### **3.3.2.6.1. Natural Phenomena**

Natural phenomena hazards (NPH) and their treatment on a plant-wide basis are included in Section 2.10 **Design Assumption**. In considering NPH, only high wind, wind missile and seismic event might influence the stability of an unprotected load. The protection afforded by the building structure against wind and wind missile is a safety function. **Safety Function**. Seismic events are a clear potential initiator for dropped load which needs to be addressed once the control strategy has been developed.

#### **3.3.2.6.2. Man Made External Hazards**

Aircraft strike needs to be assessed once the control strategy has been developed. Other man-made hazards and their treatment on a plant-wide basis are also discussed in Section 2.10. There are no man-made hazards that affect this event uniquely.

## **3.3.3. Control Strategy Development**

### **3.3.3.1. Controls Considered**

The following controls were considered to prevent or mitigate the consequences of a drop of the pump:

- Enhanced Crane Standards. The crane that moves the pump flask can provide different levels of reliability against load drop according to the standards to which it is constructed and operated. The ability to select different standards and therefore different reliabilities makes this part of the control strategy for the hazard.
- Wheeled Flask. A floor mounted guided/wheeled flask could be used in place of the crane lifted flask. This could eliminate the dropped load hazard.
- Maintenance Free Pump. As the pump's need for maintenance is the cause of the move, the use of a "maintenance free" pump is a potential control (any pump design with a lower frequency of maintenance is helpful in reducing risk).
- Qualified Flask. The pump will be moved within a shielded flask to provide operational shielding and containment. If the flask were qualified to maintain shielding and complete containment (or provide a significant decontamination factor) after a drop this would mitigate the hazard. This strategy would require that the maximum lift height used should be constrained to the drop height for which the flask is qualified.
- Bagged Pump. The pump could be contained within a bag proven to maintain its containment or provide a significant decontamination factor after a drop incident. This would mitigate the hazard.

- Flush/Wash the Pump. This is already part of the normal operation of the facility. Its contribution to a control strategy as a mitigator will depend upon its reliability and effectiveness.
- Protect Operators. If all the operators in the area of the move wear respirators then the facility worker inhalation dose would be mitigated.
- Pre-Evacuate Route. Prior removal of operators from the operating area where the flask is being moved would mitigate the facility worker dose.
- Activity in Air Alarms. The consequences to operators in the vicinity of the drop might be mitigated by the provision of activity in air alarms to prompt evacuation on detection of high beta or alpha activity in air.

### **3.3.3.2. Control Strategy Selection**

Control strategy selection was based on a two-step process: first, clearly unrealistic control elements were deleted; second, engineering tradeoffs were considered to further down-select the options, and a preferred control strategy was selected.

#### **3.3.3.2.1. Step 1 (Initial Screen)**

The merits of each of the potential controls described above were considered, primarily against the following set of criteria:

- Effectiveness
- Practicability
- Reliability
- Demonstrability
- Compliance with laws and regulations
- Ability to comply with DOE/RL-96-0006, *General Radiological and Nuclear Safety Principles* (in particular, use of proven engineering practice, ease of providing inherent/passive safety features, radiation protection features, and avoidance of undue reliance on human actions).

The objective of this review was to identify the main advantages and disadvantages of each control, and also to eliminate those which were not considered viable in formulating a composite control strategy. The results of the process are shown in the Table 3.3-1.

**Table 3.3-1. Initial Evaluation**

<b>Control</b>	<b>Advantages</b>	<b>Disadvantages</b>	<b>Compliance with Top Level Principles</b>	<b>Further Consideration in Control Strategy</b>
Enhanced Crane Standards	High integrity cranes are proven technology with well-defined standards	Increased cost	Yes	Yes
Wheeled Flask	Eliminates drop hazard (topple and collision hazards may remain)	There are concerns over consistency with plant sizing and layout proposals. Many in cell maintainable items need to be accessed on the 0-m level. Tracked or wheeled flasking may make for excessive cell top area requirements for clear track/wheeled access routes.	Yes	This option has the potential to eliminate the hazard. It will have to be considered further before a decision on its acceptance or rejection can be made. It is therefore recorded as an <b>Open Issue</b> . At present no conceptual design for its use exists. The example will proceed in the interim on the assumption of the crane lifted flask
Maintenance Free Pump	Eliminates drop hazard	The pumps under consideration have been specified as mechanical only because it has not been possible to specify a maintenance free type of pump with the required delivery characteristics (Richardson 1998).	Yes	No – but selection of a pump with minimum maintenance requirements remains a design objective. <b>Open Issue</b>
Qualified Flask	Passive	Work and cost involved in qualifying flask	Yes	Yes

**Table 3.3-1. Initial Evaluation**

<b>Control</b>	<b>Advantages</b>	<b>Disadvantages</b>	<b>Compliance with Top Level Principles</b>	<b>Further Consideration in Control Strategy</b>
Bagged Pump	Could reduce consequences	It is doubtful if it would be practicable to devise a bag that would withstand the forces involved in a pump drop. There would also be the difficulties of engineering a method of getting the pump into the bag and sealing it.	There could be significant dependence upon operator action to achieve the bagging; this may itself pose hazards or give rise to dose.	No
Flush/Wash the Pump	Reduces consequences, and does so by limiting the amount of material which leaves primary containment and hence is put at risk in the event	Depends upon administrative controls	Yes, if not the primary element of the control strategy (since administrative)	Yes
Protect Operators (respirator)	Reduces consequences for facility operator	Is operationally undesirable. Does not prevent or mitigate the actual release	Depends entirely upon operator actions and protective equipment. Is the least desirable control in the ALARA hierarchy	No
Pre-Evacuate Route	Reduces consequences for facility operators	Could prove disruptive. Does not prevent or mitigate the actual release	Depends entirely upon operator actions	No, although this does not mean that operationally this practice might not be employed

**Table 3.3-1. Initial Evaluation**

<b>Control</b>	<b>Advantages</b>	<b>Disadvantages</b>	<b>Compliance with Top Level Principles</b>	<b>Further Consideration in Control Strategy</b>
Activity in Air Alarms	May reduce consequences for facility operators	Does not prevent or mitigate the actual release. Alarms may not respond rapidly enough to prevent significant operator dose; the drop itself is a more obvious prompt for evacuation	Depends entirely upon operator actions	No, although this does not mean that this feature will not be provided in the design

The following controls remained to be considered in formulation of the control strategy to be adopted:

- Crane reliability (enhanced crane standards)
- Qualified flask
- Flush and wash pump

#### **3.3.3.2.2. Step 2 (Engineering Screen)**

The preferred strategy was then developed through an engineering evaluation of the alternatives. This took account of the following considerations to ensure a comprehensive approach in the context of other hazards and the overall design.

- Introduction of secondary hazards
- Impact on safety features provided to protect against other hazards
- Impact of other hazards upon the control strategy
- Robustness to other fault conditions and environments (including seismic and other design basis events)
- Passive or active, and if active, automatic or administrative/procedural – order of preference
- Robustness of any administrative controls required
- Cost
- Operability
- Maintainability
- Ease of justification (e.g., consistency with proven technology)

The considerations are presented in the Table 3.3-2.

**Table 3.3-2. Engineering Evaluation**

<b>Criterion</b>	<b>Crane Reliability</b>	<b>Qualified Flask</b>	<b>Flush and Wash Pump</b>
Introduction of Secondary Hazards	<p>Lifting loads produces the potential for collision with other items or collateral damage on drop. This aspect will need to be fully explored when the level of design detail necessary to identify all potential hazards is available.</p> <p>The consideration will need to extend to post drop remedial issues (e.g., how difficult would it be to seismically requalify the structure post drop, even if the drop itself produced no unacceptable risk)</p>	Represents a heavy suspended load which can exacerbate collision/drop damage	<p>Requires a connection from vessel to operating area which will require protection by a cabinet system.</p> <p><b>Design Assumption</b></p>
Impact on Safety Features Provided to Protect Against other Hazards	By physical damage on drop as above	By physical damage on drop as above	None
Impact of other Hazards upon the Control Strategy Element	None	<p>Drop of the pump from the internal hoist should not challenge the flask shielding or containment integrity</p> <p><b>Safety Function</b></p>	None
Robustness to other Fault Conditions and Environments	<p>Needs to withstand power fail and fire without load drop.</p> <p>Must withstand seismic event adequately (i.e., without this adding significantly to risk)</p>	<p>Requires lift height limits to be in place for guaranteed effectiveness.</p> <p><b>Safety Function</b></p> <p>Also requires shield door closure to be guaranteed before lift; this is achieved through mechanical interlocks. <b>Safety Function</b></p>	<p>It may be possible to envisage maloperated flushing regimes or unusual plant conditions which remove enough of the gamma emitters to render gamma monitoring for successful flushing inoperable whilst leaving the alpha emitters which are the main consequence source in place. <b>Open Issue</b></p>

**Table 3.3-2. Engineering Evaluation**

<b>Criterion</b>	<b>Crane Reliability</b>	<b>Qualified Flask</b>	<b>Flush and Wash Pump</b>
Passive or Active	Active, but of well known reliability	Flask body is passive. Shield door is passive once locked. It is mechanically interlocked against inadvertent flask removal without shield closure and locking	Active and dependent upon procedural control
Robustness of any Administrative Controls Required	Established and tested procedures	Established and tested procedures	Robust - procedure involves no significant complexity or onerous demand frequency or timescales
Cost	Cost of a high integrity, or single failure proof crane will be higher than an industrial crane	There will be costs of qualifying the flask	Not significant – system is required anyway to limit dose and contamination in maintenance facility
Operability	Well proven	Well proven	Well proven
Maintainability	Well proven	Well proven	Well proven
Ease of Justification	Proven technology	Proven technology	Proven technology

### 3.3.3.2.3. Control Strategy Selected

In selecting a control strategy there is a requirement to emphasize preventive over mitigative, passive over active, and automatic over procedural.

The primary preventive element is the crane reliability.

The qualified flask provides passive mitigation, and is the preferred element for combination with the crane.

The pump flushing and washing is active and administrative, and so is the weakest element. It does however have the strong advantage of significantly reducing the amount of active material which leaves the normal primary containment and is hence put at risk in the event. It is therefore appropriate to include it in the control strategy as an aspect of defense in depth.

The remaining choice to be made is between the “high integrity” and industrial crane. Current uncertainties regarding reliability data for U.S. cranes were referred to in Section 3.3.2.4. Furthermore, there are remaining open issues regarding the development of the load drop event sequence into damage to, and possible penetration of, the floor, discussed in Section 3.3.2.2. Also the pumps are not the only, and almost certainly not the bounding, load handled by the crane and flask combination (this being the ultrafilter tubes).

These issues will be addressed during later stages of the design and safety development. In the interim there is confidence in the ability to identify equivalence of standards, and hence reliability, between the high integrity and single failure proof crane (see Section 3.3.4.6). It is concluded that specification of a high integrity, or single failure proof, crane is currently the most appropriate and secure project solution. Safety benefits of this approach include an increased emphasis on prevention.

In summary, the control strategy is a high integrity crane to support the load **Safety Function** and a flask qualified to maintain shielding and containment post drop **Safety Function**. The pump flushing and washing is included to provide additional defense in depth through reduction in the amount of active material which is at risk in the drop **Safety Function**.

### 3.3.3.3. Structures, Systems, and Components that Implement the Control Strategy

The SSCs that implement the selected control strategy for the dropped pump flask hazard are:

- The load path elements comprising the flask, lifting beam, crane, and building structure. These are the many components that support the load. The lifting beam supports the flask through its trunnions, the crane hook supports the lifting beam, the wire rope supports the hook, the crane holds the rope, and the building supports the crane. Only the major components are listed; however, all the minor elements that bear the load are included, such as for instance the drive keys in the brake drums.
- The crane active systems which prevent load drop. These are a collection of systems that either control crane lifting and lowering in normal operation, or take control to prevent a dropped load in response to a fault. Detailed listings are derived in the standard. Typical elements are presented as design safety features in Section 3.3.4.5.2

- The flask body, including shield door, providing shielding and containment of the pump after any drop. The shield door closure is ensured by interlock involving the gamma gate which is therefore also included.
- The pump flush and wash systems which reduce the activity loading of the pump before and during withdrawal into the flask. These consist of a pipework delivery system and a reagent supply system.

### 3.3.4. Safety Standards and Requirements

#### 3.3.4.1. Reliability Targets

The reliability target for the overall control strategy is  $1 \times 10^{-6}/y$  (or  $7.6 \times 10^{-8}/\text{lift}$  for 13 lifts/y). This needs to be achieved by the combination of the preventive and mitigating parts of the strategy.

##### 3.3.4.1.1. Load path elements and crane active systems

The Sellafield reliability database figure of  $1 \times 10^{-6}/\text{lift}$  for a high integrity crane represents operational experience of complete systems. Thus a target based on this is a combined target for the 4 load path elements listed above and the active systems preventing drop. It also includes the task of attaching the flask to the crane.

The crane target reliability is proposed to be  $1 \times 10^{-6}/\text{lift}$  giving a frequency of drop of  $1.3 \times 10^{-5}/y$  for 13 lifts.

##### 3.3.4.1.2. Flask

The flask must provide the balance of the required reliability,  $(1 \times 10^{-6}) (1.3 \times 10^{-5}) = 7 \times 10^{-2}$ . This figure represents the maximum allowed probability that the flask will fail to provide containment and shielding post drop. It includes the probability of the door being open (or coming open) due to the interlock, which ensures it is closed and locked prior to the move, having failed.

##### 3.3.4.1.3. Pump flush and wash

The flushing element contributes to the defense in-depth and is active administrative. Target figures are not allocated at present, the preference being for achieving the overall target frequency through the passive and automatic systems.

#### 3.3.4.2. Performance Requirements

Overall performance requirements of the control strategy for seismic events and aircraft strike must first be developed.

It has been identified that a seismic event is a possible initiator of the load drop additional to the other causes which are covered by the UK reliability data used. It is necessary to ensure that this does not make a contribution to risk which could challenge achievement of the relevant target frequency for the event.

Design basis seismic events by definition have a frequency of  $5 \times 10^{-4}/y$  (DOE 1996 and BNFL Inc. 1998e). It is estimated based on experience that the period for which the load is suspended per lift would not on average exceed 1 hour (typical crane speeds being of the order of 10 m/minute) **Design Assumption**. The probability of a load being suspended at the time of the event is therefore (for the 13 lifts per year)  $13 / (365 \times 24) = 0.0015$ . The frequency with which a design basis seismic event could cause load drop is therefore  $5 \times 10^{-4} \times 0.0015 = 7.5 \times 10^{-7}$ . (This assessment will be valid for beyond design basis seismic events which will have a lower frequency). This is just below the target frequency for SL-1 events, and so gives rise to no seismic qualification requirements. The analysis takes no account of mitigation (which will ensure that the probability of a drop having SL-1 consequences is low) and it is therefore conservative.

Considering sub-design basis seismic events, these may have a higher frequency, and if the load is dropped because of them the frequency target may not be achieved. It is therefore necessary to specify that the crane will not drop its load in any sub design basis event such that the frequency target for the mitigated, or partially mitigated, consequences which ensue is not exceeded (**Safety Function**). This is most straightforwardly achieved by requiring the crane be seismically qualified for the design basis seismic event.

The HAR (BNFL Inc. 1998b) derives a frequency for aircraft crash into the TWRS facility as  $4.5 \times 10^{-6}$  per year. It can be seen that with a probability of load suspension of 0.0015, the frequency of load drop due to aircraft strike will be negligible at  $4.5 \times 10^{-6} \times 0.0015 = 7 \times 10^{-9}/y$ , and need not be considered further.

It is now possible to define performance requirements for each of the important to safety SSCs that implement the control strategy.

#### 3.3.4.2.1. Load path elements

The load path elements of crane, lifting beam, flask and building must:

- Support the maximum load.
- Withstand the design basis seismic event without dropping the load.

#### 3.3.4.2.2. Crane active systems

The active systems of the crane must not drop load on power failure. They must not drop the load due to any motor or control system fire or any damage resulting from it.

The active systems of the crane must protect the rope against overstressing or mechanical damage and must hold the rope in case of hoist failure. Further performance requirements are derived in the standard.

#### 3.3.4.2.3. Flask

Following the maximum height drop in the worst orientation, the containment and shielding features must be maintained. That is, the body of the flask should not be penetrated and the door and hoist seals should be intact. As a minimum, the activity released on such a drop must not be sufficient to allow consequences to remain in the SL-1 category. The unmitigated inhalation consequences are calculated in Section 3.3.2.3

as 46 rem to the facility operator. The minimum performance requirement is therefore to provide a decontamination factor (DF) of at least 2 to reduce consequences to SL-2 (<25 rem). In order to provide a margin and to give a design target, a DF of 10 is specified. Much better performance would be expected.

The above performance must also be maintained following a drop of the pump from the hoist inside the flask, which may be coincident with the flask drop.

The internals of the flask must withstand chemical attack from any of the acidic or alkaline wash and process liquors which may have been used on or with the pump.

#### **3.3.4.2.4. Pump flush and wash**

The flushing of the pump must meet the following criteria:

- Appropriate reagents must be delivered at an adequate flowrate.
- The flush and wash must be operable with a failed pump.
- The flush and wash must reduce the activity levels. Performance requirements will be quantified in consideration of acceptable levels for the maintenance facility.
- The flush and wash must be available if a re-flush is required following the failure at the monitoring position.

#### **3.3.4.3. Administrative Measures**

Administrative measures required to assure the selected control strategy are as follows:

##### Normal operations

Normal operations will be conducted in accordance with approved operational safety requirements and in strict accordance with administrative and procedural control. Operators will be trained and assessed on the conduct of normal operations. Operational procedures, routine schedules and records will augment training.

Arrangements for the examination, inspection, maintenance and testing of all ITS equipment will be managed through a plant maintenance schedule (PMS). All maintenance activities will be carried out using appropriate maintenance instruction.

##### Operator response to abnormal conditions

Operators will be trained to identify, diagnose and respond to abnormal operating conditions. Plant information will be relayed to the operator in such a manner as to aid the operator in performing this duty. Typically, any deviation of the process from its normal operating condition will generate an alarm appropriate to its importance. This alarm will annunciate at the operator workstation or locally within the facility. Operational procedures will detail the:

- Actions the operator must perform to minimize the impact of the abnormality
- The potential initiators
- The follow-up actions required, when plant conditions have been stabilized

#### **3.3.4.3.1. Load path elements and crane active systems**

The crane operational and maintenance procedures will need to be at least equivalent to the UK practices, on which the reliability data used, are based. This information will be collected. The data are, in any case, significantly based on the standards used and applicable regulations. This topic is subject to closure of the open issue related to crane standards. **Open Issue.**

#### **3.3.4.3.2. Flask**

Operators will be trained to evacuate immediately from a dropped flask event, irrespective of whether there is any apparent release and operation or any radiation alarms.

Operators will be trained not to stand in the hazard zone of any suspended load.

#### **3.3.4.3.3. Pump flush and wash**

Pump replacement is a routine operation. The pump flush and wash activity will be proceduralised in an operator instruction. The operator instruction provides a systematic approach to performing all the necessary activities to complete the task. The operator instruction will detail roles and responsibilities, levels of authority, hazards and precautions, and operational decision points.

The key steps associated with the pump wash and flush are:

- Flush out of the pump prior to removal
- Pump washing during removal

The operational decision point of determining when washout is complete is the drop in radiation levels associated with the pump. The acceptance criteria will be detailed within the Operation Instruction.

#### **3.3.4.4. Administrative Standards**

Operation of the TWRs facilities shall be conducted in accordance with proven practices from BNFL operations in the UK and the US. Arrangements will be in place to maintain and demonstrate compliance with all safety criterion detailed within the authorization basis.

The conduct of operation guidelines will be generated by the tailored application of appropriate sections of the following standards:

- Management and organizational structure
- Documents, records and certification, including response to abnormal operating conditions, key compliance recording and archiving

- Structured training programs for all personnel, tailored to their roles and responsibility
- Emergency preparedness implemented by having an emergency response structure, training, exercises and procedures.
- Incident reporting arrangements.
- Safety documentation hierarchy, with appropriate flow down of information into operational documentation. All safety implications will be clearly identifiable within the operational procedures.
- Quality assurance.
- Arrangements for the examination, inspection, maintenance and testing of all ITS equipment.
- Labeling of ITS equipment clearly on the facility.

#### **3.3.4.5. Additional Design Safety Features**

The following design safety features apply in addition to those already noted.

##### **3.3.4.5.1. Load path elements**

The ability of the building fabric to protect the crane from high wind or wind missile effects is a safety function protecting the crane. This will be achieved by the application of the standards listed for the building load path.

##### **3.3.4.5.2. Crane active systems**

(This list is based on the BNFL high integrity crane; see open issue on crane standards.)

#### **1. Hoist Protection Devices**

- a. Hoist operating limits  
A rotary/hunting tooth limit switch system is used with 3 settings: raise slow down , over raise and over lower. On action of the over raise or lower the hoist motor control circuit is de-energized.
- b. Eddy Current Brake (ECB) (Speed Control)  
This is the active part of the speed control system and reduces demand and wear on the conventional brakes.
- c. Service and back-up Thruster Brakes  
There are 2-off identical brakes on the input shaft of the gearbox timed to operate with the service brake coming on first and the second, coming in as back-up, a very short time latter.
- d. Emergency Rope Barrel Brake Calipers  
These calipers (quantity as required) act on the rope/cable barrel as a final emergency brake.

- e. Hoist ultimate over raise  
This is a limit switch with a detector bar which actual contacts the lower block in the ultimate over raise position wired to cut the power circuit to the hoist.
  - f. Slack rope protection  
This is a limit switch with a rope/cable tension detector. When a slack rope/cable is detected (which could mean a load has become snagged and if allowed to fall on a significant length of slack rope, it could impose an impact load on the load path elements) the control circuit is de-energized.
  - g. Overload protection  
This is trip level taken off the load cell output and prevents the hoist from lifting above its SWL.
  - h. Over speed protection  
If over speed is detected the hoist is stopped.
2. Cross Traverse Protection Devices
- a. Traverse Normal Operating Limits  
Limit switch wired into the control circuit for the cross travel.
  - b. Over Traverse Ultimate Limit  
Limit switch wired into the power circuit for the cross travel.
3. Long Travel Protection Devices
- a. Travel Normal Operating Limits  
Limit switch wired into the control circuit for the long travel.
  - b. Over Travel Ultimate Limit (series)  
Limit switch wired into the power circuit for the long travel.
4. General Crane Safety/Protection Features
- a. Hard-wired Emergency Stop System.
  - b. Operator Control Stations.

#### **3.3.4.5.3. Flask**

The flask can only be guaranteed to achieve its shielding and containment performance requirements for drop height within its qualified limit. This will be achieved by passive means, i.e. the location of the crane and the length of the lifting beam in relation to the floor.

#### **3.3.4.5.4. Pump flush and wash**

The radiation monitor prompts the operator to return pumps carrying excessive activity into their casing for further flush and wash operations.

The reagents will be sampled to ensure they are the correct composition.

A flowmeter will be used to indicate that an adequate supply of reagent is being delivered

#### **3.3.4.6. Design Standards**

The following section develops the design standards for the selected SSCs but has not listed all the material and minor component standards (e.g., bolts).

Design guides were consulted to establish an appropriate starting point for the designer to identify standards.

##### **3.3.4.6.1. Load path elements and crane active systems**

The reliability target assigned to this grouping is based on data for cranes at BNFLs Sellafield site in the UK. To have confidence in achieving this figure, the design standards must be better than or equivalent to those used for the cranes and structures which have produced the reliability figure.

Table 3.3-3 shows the comparison of appropriate design standards used in the specification of the UK systems with an “equivalent” U.S. specification. The general equivalence of standards is confirmed, though with specific items still requiring resolution. **Open Issue.**

**Table 3.3-3. Comparison of Design Standards**

<b>Element</b>	<b>Standards associated with reliability figures.</b>	<b>Standards for TWRS-P</b>	<b>Comments</b>
Crane load path and active systems	BS 2573 Rules for the design of cranes. BS466 Classification of cranes. BS 5237 Specification for lifting twistlocks. MHS/SC/001 Mechanical and structural design requirements (nuclear use). In addition, the following features are included in the design: <ul style="list-style-type: none"> <li>• Counterwound hoist cables</li> <li>• Dual braking systems</li> <li>• Minimum 3 turns of rope on at full drop</li> <li>• Down rated permissible stresses</li> </ul>	ASME NOG-1-1995 with possible BNFL selected qualifications	A detailed comparison of the crane standards shows that ASME NOG-1-1995 is generally equal to or better than the UK standards. Specific areas related to single failure proofing are still under discussion. <b>Open Issue</b>
Flask load path	BS 2573 Rules for the design of cranes (structures & mechanisms).. BS 466 Classification of cranes NF0082/7 Trunnion and lifting beam design also uses KTA3905, KTA3902 & KTA3903 and NUREG-0554 criteria.	Appropriate sections from ASME NOG-1-1995 e.g., sections NOG-4310 to 4413 and NOG-5300 to 5320 Trunnion and lifting beam ANSI N14.6 1993. Special Lifting Devices for Shipping Containers Weighing 10,000 pounds or More.	The sections selected from the various standards are dependent on the detail form of the flask system. If a feature is required that a standard is not available for then some combination will be developed and worked from first principles.

#### 3.3.4.6.2. Building load path

In order to provide adequate support for the high integrity crane preventing the load drop, the structural steel and concrete structure supporting it will be designed for the natural phenomena hazard (NPH) event. Since the integrity of the structure is required to ensure worker and public safety, the structure is categorized as PC-3, in accordance with DOE-STD-1021, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*. The NPH event loads will be determined in accordance with the following codes and standards:

DOE-STD-1020, "Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities"

ASCE 4, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary"

ASCE 7, "Minimum Design Loads for Buildings and Other Structures"

The concrete cell structure and surrounding steel structure supporting the crane will be designed for the loads from the references noted above. The structural steel and concrete will be designed in accordance with the following:

ANSI N690, "Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear facilities"

ACI 349, "Code Requirements for Nuclear Safety Related Concrete Structures"

#### 3.3.4.6.3. Flask

The flask will be a specific design to the following standards in order to satisfy the shielding and containment requirements:

- NF0082/7, Radiological Requirements - double seals
- NF0115/1 & NF0115/2, Elastomeric Seals – radiation tolerant
- Structural requirements tailored from a crane standard (e.g., ASME NOG-1-1995)

Further requirements for the flask are to provide a DF post drop of at least 10 with a probability of failing to achieve this no greater than 0.07. This requires that the loading and factors associated with a specified maximum drop height are also acknowledged. An approved dynamic stress analysis code e.g., Dyna 3D would be used to analyze the flask containment features when subjected to the worst case drop. (Allowable stresses will be taken from ASME NOG-1-1995, e.g., sections NOG-4310 to 4413 and NOG-5300 to 5320 ). This method of analysis has been confirmed by drop testing.

A further development of standards could involve design to full external transport requirements to survive the specified fire, collision, drop onto spike etc. The flask design would then be physically tested against the specified challenges. This is considered unnecessary for the internal use and limited performance requirements of the flask. Major fire hazards, high speed collisions, and puncture hazards will not apply within the flask movement zone. **Design Assumption.**

A design safety feature associated with the flask is the interlock, which prevents it from being lifted without the door closed and locked. The diverse mechanical/electrical interlock is a specific design. In essence it will ensure that the door opening mechanism is obstructed by the lifting beam and is inaccessible until the lifting beam has been removed. Similarly, operation of the door opening mechanism will obstruct the trunnions and will prevent the lifting beam being reattached until the door is closed and locked. Electrical interlocks will also ensure that the doors have to be locked closed before an attempt can be made to physically move the mechanical interlock which obstructs attachment of the lifting beam. The following standards will be applied:

ISA S84.01      Application of Safety Instrumented Systems for the Process Industries.  
NF0141/1      Design Principles for Gamma Gate Systems

#### **3.3.4.6.4.    Pump flush and wash**

The flushing system will be designed to the following standards:- ASME B31.3, "Process Piping," and ASME Section VIII, "Boiler and Pressure Vessel Codes, Rules for Construction of Pressure Vessels," along with K70DG633 (BNFL Inc. 1998a) for wash cabinets.

#### **3.3.4.6.5.    Standards not in the Safety Requirements Document**

The following standards referenced in this report are not contained in the SRD:

ASME NOG-1-1995  
Rules for the construction of overhead and gantry cranes (Top Running Bridge, multiple girder)

ANSI N14.6-1993  
Special lifting devices for shipping containers weighing 10,000 pounds (4,500kg) or more.

#### **Company Standards**

NF 0082/7 Health Physics guidance notes for designers  
NF 0141/1 Design principles for gamma gate systems.  
NF 0115/1 and 2 Elastomeric Seals – Radiation Tolerance

### **3.3.5. Control Strategy Assessment**

#### **3.3.5.1.    Performance Against Common Cause and Common Mode Effects, and Design Basis Events**

The strategy has specific performance requirements to ensure adequate safety in respect of wind, wind missile and seismic event. These are achieved through the selected standards for the building structure and the crane.

Performance requirements have also been set against the identified common cause issues of power failure and electrical fire for the crane. Again the selected standards achieve these requirements. The braking

systems operate automatically in the event of power loss due to any cause, and there is separation between the braking elements such that no local fire would be likely to be able to disable all sets. A fire that caused loss of power would in fact activate the brakes. These details will be confirmed during design development.

### **3.3.5.2. Comparison with Top Level Principles**

The strategy has been evaluated against a set of relevant top level radiological, nuclear and process safety standards and principles (DOE-RL 1998b), as laid out below.

#### **3.3.5.2.1. Defense in Depth (DOE/RL-96-0006 4.1.1)**

Defense in depth is one of the general radiological and nuclear safety principles in DOE/RL-96-0006. SRD Volume II, Appendix B contains the BNFL *Implementing Standard for Defense in Depth*. This Implementing Standard governs application of the defense in depth principle on the TWRS-P project.

To satisfy the application of defense in depth, the Implementing Standard requires that the elements of the control strategy must ensure "...that no one level of protection is completely relied upon to ensure safe operation. This safety strategy provides multiple levels of protection to prevent or mitigate an unintended release of radioactive material to the environment."

DOE/RL-96-0006 formulates the defense in depth principle in terms of the following six sub-principles:

- Defense in depth
- Prevention
- Control
- Mitigation
- Automatic Systems
- Human Aspects

SRD Volume II, Appendix B contains the BNFL *Implementing Standard for Defense in Depth*. This implementing standard governs application of the defense in depth principle on the TWRS-P project and addresses each of the six sub-principles in DOE/RL-96-0006. The following paragraphs describe application of the Implementing Standard for Defense in Depth to the control strategy for pretreatment pump drop.

##### 1. Defense in Depth (DOE/RL-96-0006 4.1.1.1)

DOE/RL-96-0006, Section 4.1.1.1, requires the following:

*"To compensate for potential human and mechanical failures, a defense-in-depth strategy should be applied to the facility commensurate with the hazards such that assured safety is vested in multiple, independent safety provisions, not one of which is to be relied upon excessively to protect the public, the workers or the environment. This strategy should be applied to the design and operation of the facility."*  
(DOE/RL-96-0006, Section 4.1.1.1)

Section 3.0 of the BNFL *Implementing Standard for Defense in Depth* addresses this aspect of the defense in depth principle specifically. For SL-1 events, Section 3.0 of the *Implementing Standard for Defense in Depth* requires:

- Two or more independent physical barriers to confine the radioactive material
- Application of the Single failure criterion
- A target frequency of  $<1.0 \times 10^{-6}$  per year for the SL-1 consequences

The control strategy provides a single physical barrier against the release of radioactivity as a result of the drop event. This barrier is the qualified flask. This represents an exception to the *Implementing Standard* requirement. However, the analysis shows that the control strategy meets the consequence and frequency targets with margin. The exception to the *Implementing Standard* requirement is justified on this basis.

The *Implementation Standard* requires application of the single failure criterion to active SSCs. The single failure criterion requires that, given an initiating event, the control strategy must be able to tolerate a single active failure in any active component in the short term. The control strategy must also be able to tolerate a single passive failure in the long term. The single passive failure is to be a mechanistic failure (for example, pump seal leakage); the single passive failure is not a deterministic failure (for example, pipe break).

The initiating event in this example is the load drop. Given the initiating event, the control strategy credits no active components. Therefore, there are no single failures in the short term. There is no impediment to rapid recovery from this accident. Therefore, there is no need to consider single passive failures. Therefore, the control strategy satisfies the single failure criterion.

The analysis in section 3.3.5.6 indicates that the control strategy reduces the frequency of SL-1 level consequences to less than the target frequency of  $1 \times 10^{-6}$  per year.

The analyses in sections 3.3.5.3 and 3.3.5.4 show that the mitigating elements of the control strategy reduce the consequence from a load drop to SL-3 levels for the facility worker and to levels well below the SL-4 limit for the co-located worker and the public. The frequency of a load drop is  $1.3 \times 10^{-5}/y$  which is well within the *Implementing Standard* target frequency of  $1 \times 10^{-2}/y$  for SL-3 events.

Based on the results of the frequency estimate, the control strategy meets the target frequency. Also, the frequency estimates indicate that the control strategy does not place excessive reliance on any single element to achieve this result.

## 2. Prevention (4.1.1.2)

Principal emphasis is placed on prevention. The primary means of preventing the accident is the provision of a "high integrity" crane that gives an acceptably low frequency of load drop (taking account of mitigation).

## 3. Control (4.1.1.3)

The frequency of demands placed upon the active important to safety SSCs within the crane system (e.g., emergency braking) and the passive SSCs of the flask structure is low due to the inherent controls of

operating a reliable crane within its proven and tested limits and in a defined maintenance regime. Failure of the pump flush and wash systems to adequately remove activity from the pump is alarmed by an installed radiation monitor.

#### 4. Mitigation (4.1.1.4)

The pump flushing limits the material at risk in any accidental release and the qualified flask provides mitigation in an accident.

#### 5. Automatic Systems (4.1.1.5)

The active SSCs on the crane which reduce load drop frequencies in maloperation or accident conditions are automatic. The interlocking of the flask door to ensure closure before the flask is lifted is mechanical backed up by an electrical interlock.

#### 6. Human Aspects (4.1.1.6)

The human aspects associated with crane and flushing operations follow proven examples and will be executed within the project procedures for training, qualification, and quality assurance. The flush/wash, flask and crane systems are well proven and simple to operate and maintain.

Since the Severity Level for the dropped load hazard is SL-1, per Section 2.6.2 of the *Implementing Standard for Defense in depth*, the control strategy must be reviewed against the human factors engineering criteria in IEEE Std. 1023-1988 6.1.1, as tailored by the *Implementing Standards*. **Open Issue.**

### **3.3.5.2.2. Operating Experience and Safety Research (4.1.2.4)**

The adopted methods build on operating experience.

### **3.3.5.2.3. Proven Engineering Practices (4.2.2.1)**

The design is based on proven equipment and practices.

### **3.3.5.2.4. Common Mode/Common Cause Failure (4.2.2.2)**

Potential common cause/mode weaknesses identified for the strategy selected have been discussed in Section 3.3.5.1. The analysis will continue as the design detail develops.

### **3.3.5.2.5. Safety System Design and Qualification (4.2.2.3)**

The operating conditions for the SSCs are known and addressed in the design. Effects such as aging are well characterized for equipment of the type selected.

#### **3.3.5.2.6. Radiation Protection Features (4.2.3.2)**

The flask and the pump flushing are specifically designed to protect workers from radiation exposure. The control strategy has been subjected to an ALARA design review which concluded that the selected strategy has no adverse ALARA impact (Pisarcik 1999).

#### **3.3.5.2.7. Deactivation, Decontamination, and Decommissioning (4.2.3.3)**

The presence of the crane, flask, and pump flushing facilities will aid in plant decontamination and decommissioning, and do not in themselves complicate Deactivation, Decontamination, and Decommissioning.

#### **3.3.5.2.8. Emergency Preparedness - Support Facilities (4.2.4)**

The strategy has no foreseeable impact on the control room or emergency response center that may require to be manned after an event.

#### **3.3.5.2.9. Inherent/Passive Safety Characteristics (4.2.5)**

The flask provides passive safety, with the crane providing proven reliability.

#### **3.3.5.2.10. Human Error (4.2.6.1)**

The potential for human error giving rise to consequences is addressed through the active SSCs of the crane and the monitoring to provide warning of failure to flush the pump.

#### **3.3.5.2.11. Instrumentation and Control Design (4.2.6.2)**

Instrumentation is provided to assist the operator with pump flushing and to control the crane and alert the crane operator to abnormal situations.

#### **3.3.5.2.12. Safety Status (4.2.6.3)**

The strategy adopted is unlikely to have a significant bearing on control room safety status display.

#### **3.3.5.2.13. Reliability (4.2.7.1)**

Reliability targets have been assigned for important to safety SSCs in Section 3.3.4.1

#### **3.3.5.2.14. Availability, Maintainability, and Inspectability (4.2.7.2)**

BNFL has extensive experience of applying inspection, testing, and maintenance regimes to cranes and flasks. In the case of cranes in particular a very significant amount of well-characterized guidance is available from external bodies.

### **3.3.5.2.15. Pre-Operational Testing (4.2.8)**

The control strategy is amenable to pre-operational testing of its elements, and experience of this exists for these elements.

### **3.3.5.3. Mitigated Consequences**

No credit is taken for flushing and decontamination of the pump. A minimum DF of 10 has been specified for the flask on drop from its qualified lift height.

The consequences are developed in Calculation W375-NS00003 (Smith unpublished). The following is a summary of the results:

#### Facility Worker

The total worker dose is 4.6 rem. This is inhalation dose, since a performance requirement of the flask is to retain its shielding ability post drop.

#### Co-located Worker

Inhalation Dose =  $7.0 \times 10^{-3}$  rem

#### Public

Inhalation Dose =  $1.1 \times 10^{-5}$  rem

### **3.3.5.4. Frequency of the Mitigated Event**

The frequency of drop has been estimated in Section 3.3.2.4 as  $1.3 \times 10^{-5}/y$  for all pump lifts with a high integrity crane. Since it is estimated based on operational data it encompasses common cause and mode effects. This is within the lowest target frequency for the mitigated consequences described above ( $1 \times 10^{-2}$  for the facility worker).

### **3.3.5.5. Consequences with Failure of the Control Strategy (Including Mitigation)**

This is equivalent to that discussed in Section 3.3.2.3. The following is a summary of the results of the consequence calculation presented:

#### Facility Worker

Total Dose = 46 rem (SL-1)

#### Co-located Worker

Inhalation Dose = 0.07 rem (SL-4)

#### Public

Inhalation Dose =  $1.1 \times 10^{-4}$  rem (SL-4)

#### **3.3.5.6. Frequency of the Control Strategy Failure**

The frequency of the drop has been estimated at  $1.3 \times 10^{-5}/y$ . Failure of the flask to provide an adequate DF would not be expected, however the strategy will still be adequate provided that the probability of failure to provide it is lower than its performance requirement of  $7 \times 10^{-2}$ . This would ensure that the unmitigated event frequency remains below the target of  $1 \times 10^{-6}$  ( $1.3 \times 10^{-5} \times 7 \times 10^{-2} = 9 \times 10^{-7}$ ) for the SL-1 event. This takes no credit for the flushing of the pump, which would also have a low probability of failure. The frequency of the unmitigated consequences are therefore expected to be significantly less than  $1 \times 10^{-6}$ . The following table summarizes the results for this event.

**Summary of Results (Mitigated)<sup>a</sup>**

Population	Dose (rem)	Severity Level	Frequency (y <sup>-1</sup> )
Facility Worker	4.6	SL-3	$1.3 \times 10^{-5}$
Co-located Worker	$7 \times 10^{-3}$	SL-4	$1.3 \times 10^{-5}$
Public	$1.1 \times 10^{-5}$	SL-4	$1.3 \times 10^{-5}$

Note:

a. Dominant pathways selected in each case.

**Summary of Results with Failure of Control Strategy<sup>a</sup>**

Population	Dose (rem)	Severity Level	Frequency (y <sup>-1</sup> )
Facility worker	46	SL-1	$<1 \times 10^{-6}$
Co-located worker	0.07	SL-4	$<1 \times 10^{-6}$
Public	$1.1 \times 10^{-4}$	SL-4	$<1 \times 10^{-6}$

Note:

a. Dominant pathways selected in each case.

### **3.3.6. Conclusions and Open Issues**

A control strategy and associated SSCs, design safety features, and standards has been developed which is capable of providing an acceptable level of protection against the potential hazard of a dropped HLW pump within the TWRS-P pretreatment facility. Table 3.3-4 shows a summary of the main aspects of the strategy.

A number of open issues have been identified for further investigation and resolution as part of design development. These are:

1. Development of the Event Sequence. The falling flask might (i) damage equipment on the cell roof or (ii) penetrate the cell roof and damage in cell equipment. In either case there could be additional consequences due to further release of activity, and there could be damage to important to safety equipment with implications for the control of other hazards.

In the first case, when detailed design information becomes available concerning the equipment located on the cell roof which could conceivably be impacted by a dropped or misrouted flask an appropriate evaluation of the hazards this could present will be conducted. Control strategies will be developed appropriate to the hazard. These may include limit switching to control the horizontal crane routes or impact protection of equipment.

In the second case, damage to equipment below the cell roof is only possible in the event that either penetration of the roof, or significant spalling of material from inside of the roof occurs because of the impact. Such consequences are highly undesirable from a facility, as well as a safety standpoint. It is felt that the most appropriate solution to this is likely to be to design the floor to withstand the impact. The same philosophy is employed in the Sellafield Drypac Plant design to address a similar issue.

A number of technical matters and options relating to this remains to be closed out. Clearly the final weight of flask and the qualified lift height are important. Local strengthening or impact protection/load spreading, possibly coupled with further height restriction outside protected zones may be viable alternatives to general floor slab design. Commercial factors, such as ability to seismically reanalyze the building, post any drop, may also influence the choice.

2. Related Event Squares. Three related hazards and attendant event sequences need to be completed during design. These are (i) collision of the flask with other equipment during the move (but without load drop), (ii) drop of the pump back into the cell or maintenance facility during transfer into or out of the flask, and (iii) drop of the pump within the flask (from the internal flask hoist).
3. Crane Reliability Data. Relevant and verifiable data on U.S. industrial and single failure proof crane reliability is being sought.
4. Equivalence of Crane Standards. Consideration of the differences between U.K. high integrity and U.S. single failure proof crane standards is continuing as a "crosswalk" exercise. Final resolution will occur during the crane procurement process. Related is evaluating the equivalency of crane operations and maintenance procedures.
5. Tracked Flask. The concern that a tracked or wheeled floor mounted flask is inconsistent with viable plant sizing and layout strategies needs to be confirmed. A design review is required when sufficient detail is available.
6. Low Maintenance Pump. The possibility of reducing risk (and cost) by identifying a pump with lower maintenance requirements is still being pursued. This would not affect the adequacy of the control strategy developed.
7. Monitoring Effectiveness. The possibility that a wrongly executed flushing regime could remove the gamma emitters which are most readily monitored to indicate successful flushing, without removing a similar proportion of the alpha emitters, which dominate consequence, needs to be investigated.

8. Pump Activity Loading. Further review of operational and simulation data will be conducted to establish whether a more direct basis for estimation of pump activity loading and physical nature of the activity (affecting ARF and RF) can be established.
9. Human Factors Review. The control strategy must be reviewed against the human factors criteria in IEEE Std. 1023-1988 6.1.1 as tailored by the Implementing Standard for Defense in Depth.

In addition to the open issues listed above, various design and operational assumptions are highlighted in the report. Their continuing validity will be monitored through design development.

**Table 3.3-4. Control Strategy Summary**

<b>Hazard Description:</b> Drop of flask carrying pretreatment pump				<b>Initiator:</b> Crane failure causing load drop	
<b>Selected Control Strategy</b>	<b>Important to Safety SSCs</b>	<b>Safety Functions</b>	<b>Design Safety Features</b>	<b>Design Assumptions</b>	<b>Operational Assumptions</b>
High integrity (or single failure proof) crane		System: To support the load		Crane safety features are at least equivalent to those applying to the BNFL "high integrity" on which the reliability data is based  Pump moves occur 13 times per year on average  The period for which the load is suspended will not exceed an average of 1 hour per lift	Operator training and competency, and procedural and maintenance arrangements are at least equivalent to the BNFL practice on which the reliability data is based
	Load path elements	To support the maximum load To withstand the design basis seismic event without load drop	Seismic qualification  Building structure provides protection against wind and wind missile		
	Crane active systems See Section 3.3.4.5.2 for listing	To hold the load on power fail To hold the load in any motor or control system fire To prevent rope mechanical damage or overstressing, or hoist failure, leading to load drop	See list in Section 3.3.4.5.2  Separation of braking elements provides protection against local fire damage		
Qualified flask		System: To maintain shielding and containment post drop			Operators will be trained to evacuate immediately from a dropped flask, irrespective of whether there is any apparent release and of operation of radiation alarms  Operators will be trained not to stand in the hazard zone of a suspended flask

**Table 3.3-4. Control Strategy Summary**

<b>Hazard Description:</b> Drop of flask carrying pretreatment pump				<b>Initiator:</b> Crane failure causing load drop	
<b>Selected Control Strategy</b>	<b>Important to Safety SSCs</b>	<b>Safety Functions</b>	<b>Design Safety Features</b>	<b>Design Assumptions</b>	<b>Operational Assumptions</b>
	Flask body and shield door	<p>To provide a DF of at least 10 following a drop from the maximum height in the worst orientation</p> <p>To maintain shielding following a drop from the maximum height in the worst orientation</p> <p>To withstand drop of the pump from the hoist inside the flask coincident with the flask drop</p> <p>To withstand chemical attack by the acid or alkaline wash or process liquors which may have been used on or with the pump</p>	<p>The crane and lifting beam are configured to passively ensure that the flask cannot be lifted beyond the height for which it is qualified to withstand drop</p> <p>Double seals are used on the flask door</p>	<p>The maximum drop height is limited to the lift height – i.e., all the cell access plugs are on the same level</p> <p>Only one lift is required for the move of the flask and pump to the maintenance facility</p> <p>The pump holds 2 liters of solids when withdrawn unwashed</p> <p>P32001 is the largest pump handling slurry at the maximum solids concentration</p> <p>The transfer route poses no hazards of spikes, other vehicles or major fire potential</p>	
	Gamma gate and interlock	To ensure that the flask cannot be lifted unless the shield door is locked closed	Diversity. Mechanical interlock backed up by electrical interlock		
C. Pump flush and wash		System: To reduce the amount of activity which is at risk in a drop	Monitor which alarms on detection of excessive activity on the withdrawn pump.		<p>The pump will be flushed prior to removal.</p> <p>The pump will be washed during removal</p> <p>In the event of alarm of the radiation monitor the pump will be returned to its casing and the flushing/washing repeated</p>
	Pipework	To supply flush and wash liquors to the pump	A flowmeter will indicate that liquor is flowing at the required rate		
	Reagent supply system	To deliver appropriate flush and wash reagents to the pipework.	Reagents will be sampled to confirm that they are the correct composition	A cabinet system is provided to protect against back - flow and back – migration of activity	

**Table 3.3-4. Control Strategy Summary**

<b>Hazard Description:</b> Drop of flask carrying pretreatment pump				<b>Initiator:</b> Crane failure causing load drop	
<b>Selected Control Strategy</b>	<b>Important to Safety SSCs</b>	<b>Safety Functions</b>	<b>Design Safety Features</b>	<b>Design Assumptions</b>	<b>Operational Assumptions</b>
<b>Items not arising from the Control Strategy</b>					
Cell roof - impact protection or resistance	Not defined yet	To ensure that significant worsening of consequences of drop, due to damage to equipment in cell beneath, does not occur	TBD by further analysis	TBD by further analysis	TBD by further analysis
Equipment on cell roof – impact protection or resistance	Not defined yet	To ensure that significant worsening of consequences of drop, due to damage to equipment on cell roof, does not occur	TBD by further analysis	TBD by further analysis	TBD by further analysis

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a Copies of these references accompany this deliverable.

b For access to these documents, contact the Design Safety Features Point-of-Contract through the office of Safety and Regulatory Programs, TWRS-P, Richland, Washington.

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**Figure 3.3-1. Diagram Showing A Typical Remotely Maintainable Pump**

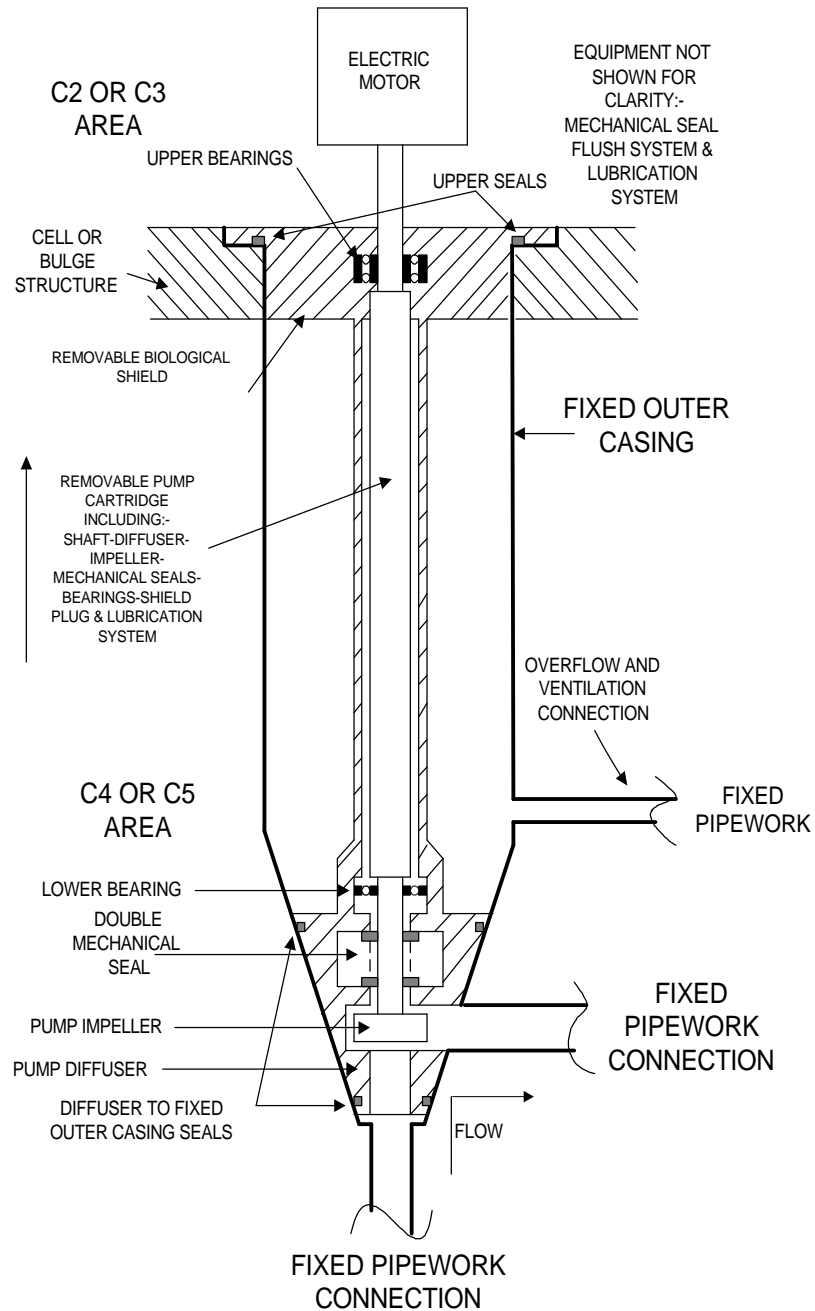


Figure 3.3-2. Partial Plan at 0 m Elevation

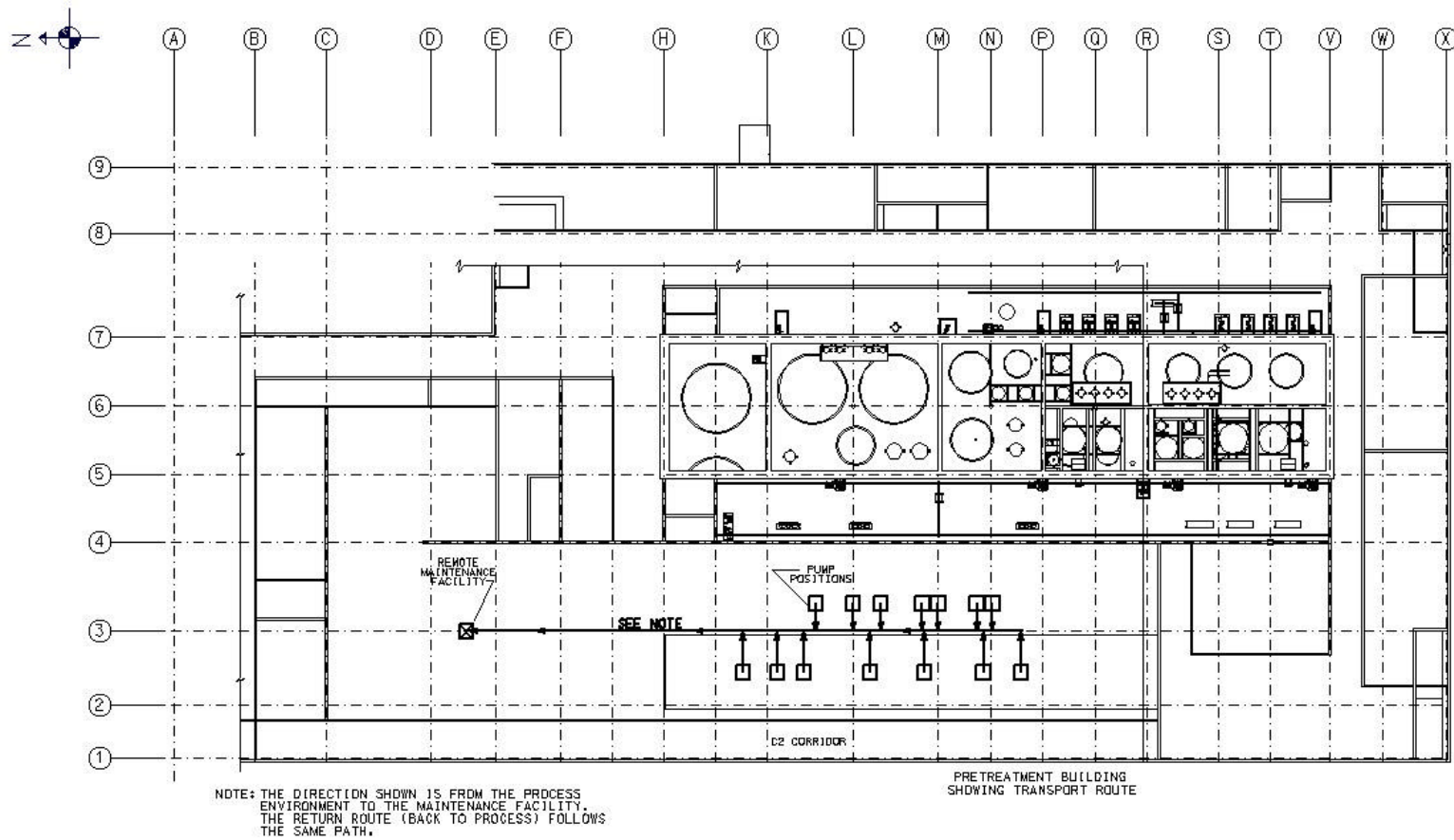
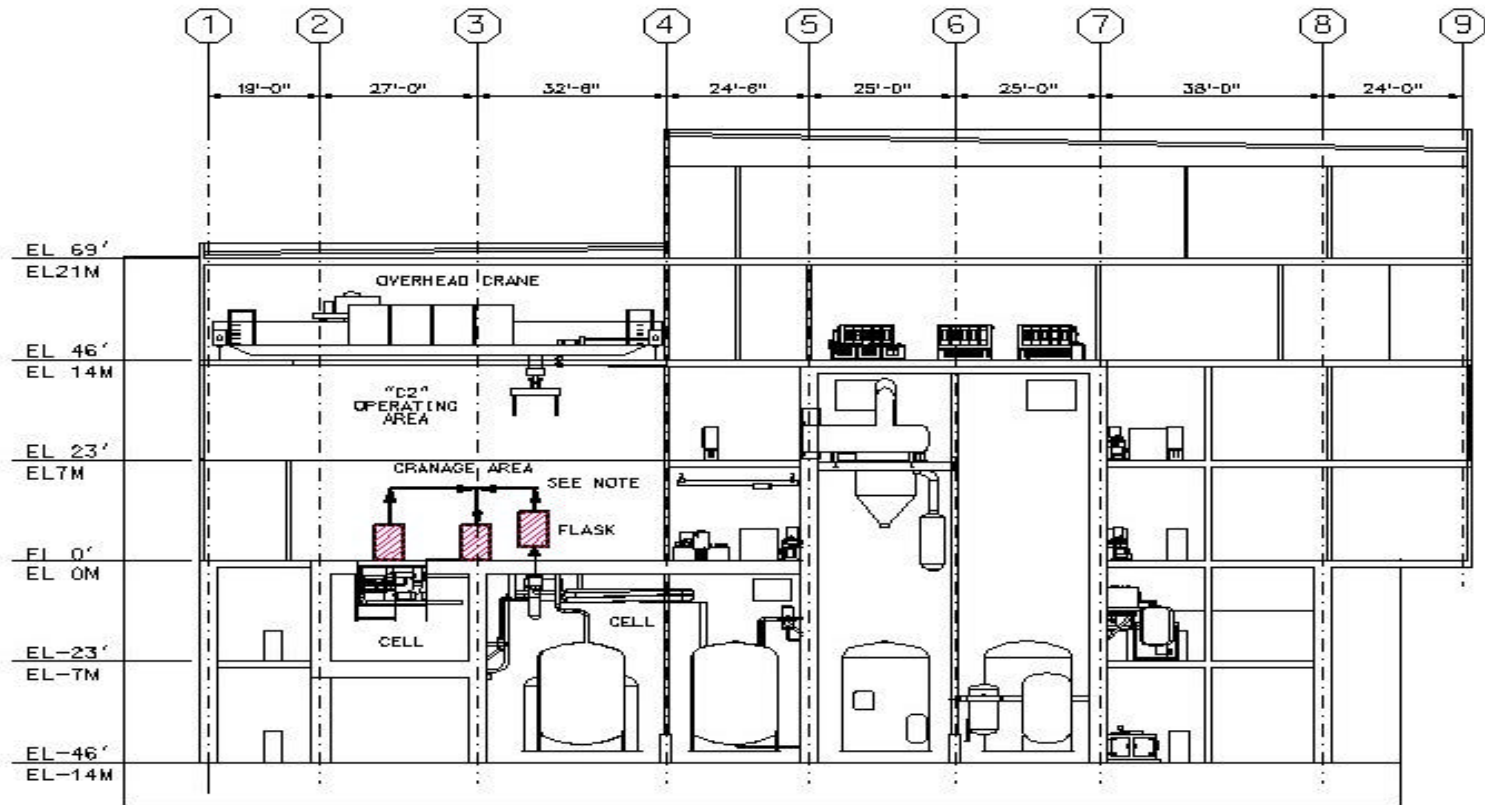


Figure 3.3-3. Column Line M Looking North



NOTE: THE DIRECTION SHOWN IS FROM THE PROCESS ENVIRONMENT TO THE MAINTENANCE FACILITY. THE RETURN ROUTE (BACK TO PROCESS) FOLLOWS THE SAME PATH.

PRETREATMENT BUILDING  
SHOWING TRANSPORT ROUTE

Figure 3.3-4. Column Line 3 Looking East

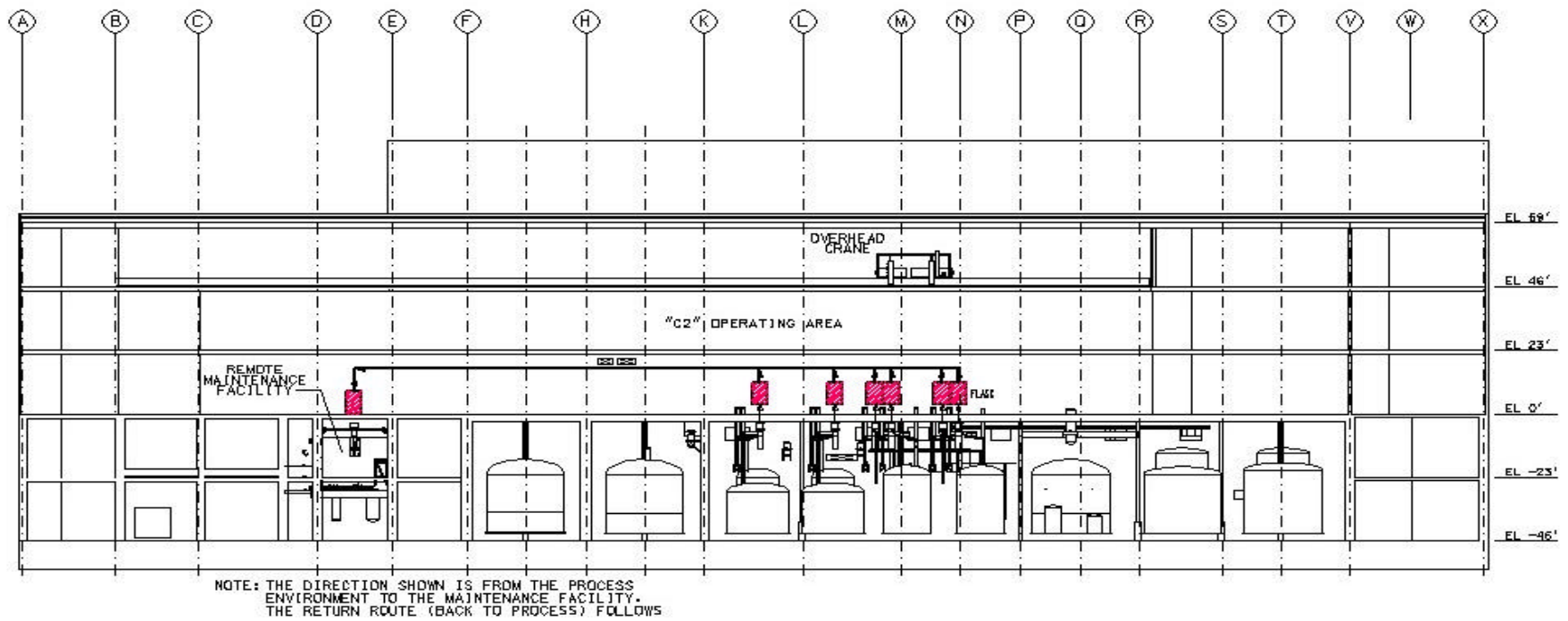


Figure 3.3-5. Layout of Typical BNFL Flashing System

